National Renewable Energy Laboratory
Innovation for Our Energy Future

Wind Energy

BLM Renewable Energy Summit

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August 31, 2009

Topics

Introduction

Review of the Current Wind Market

Drivers for Wind Development

Wind Characteristics

Wind Power Potential

Basic Wind Turbine Theory

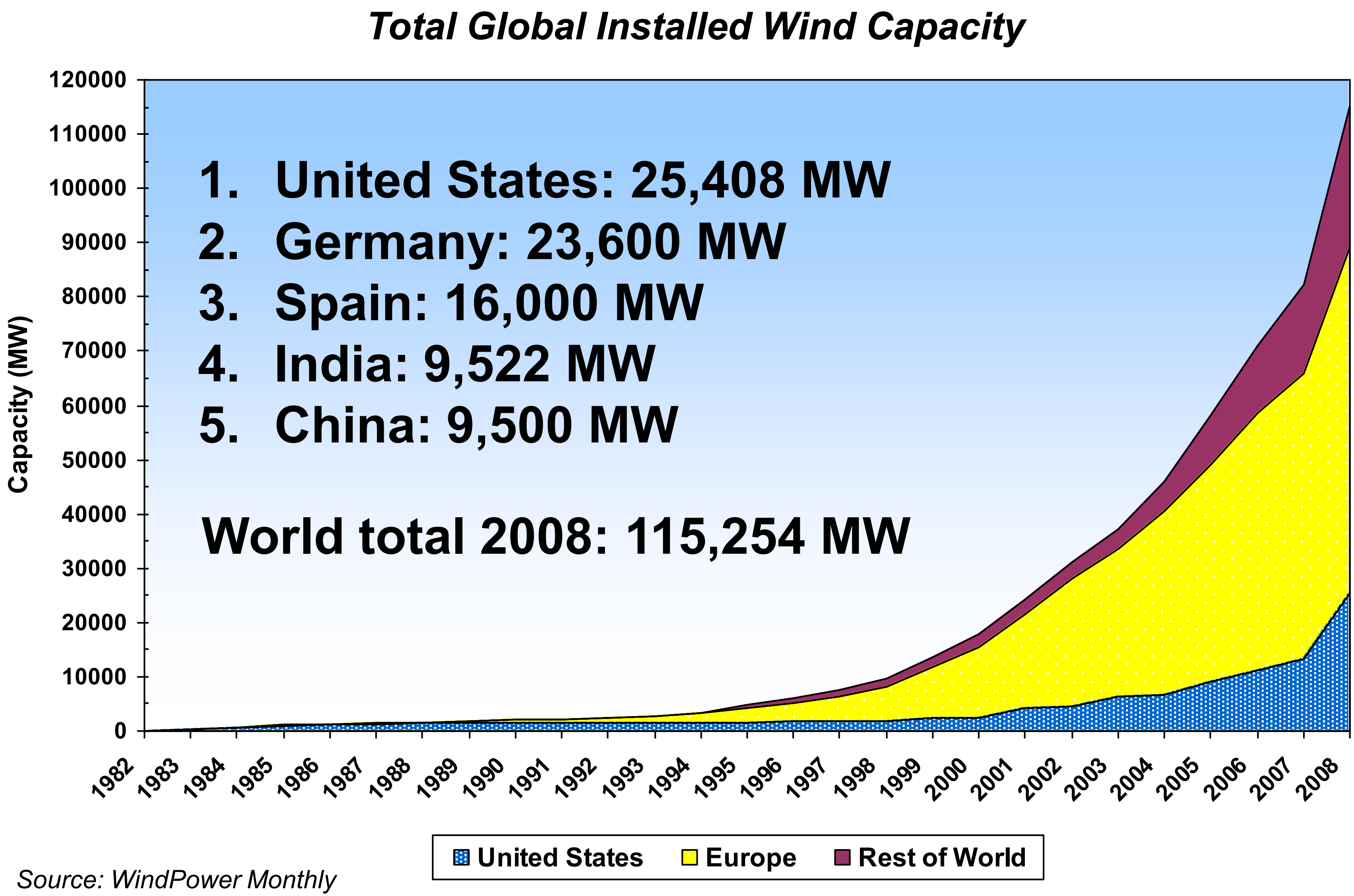
Types of Wind Turbines

Facts About Wind Siting

Wind Performance

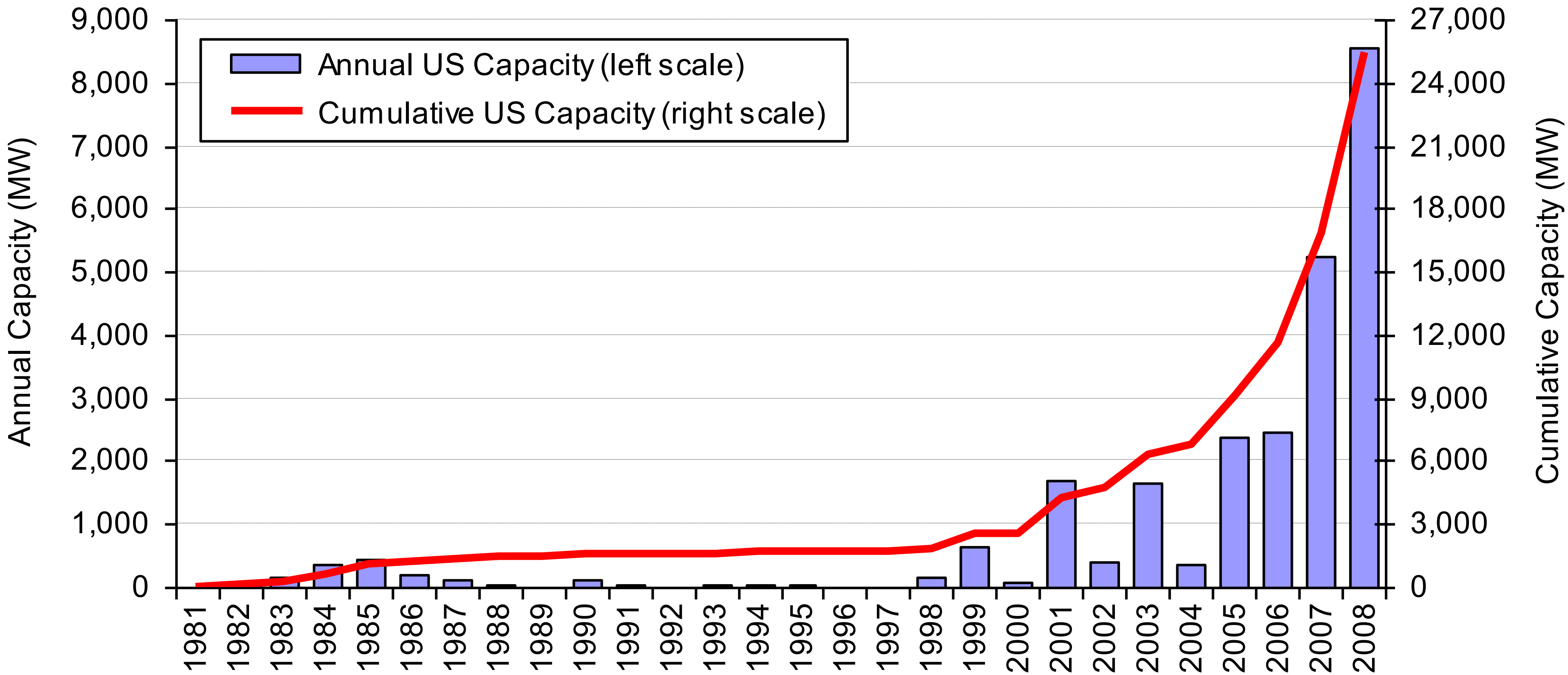
Further Information

Current Status of the Wind Industry



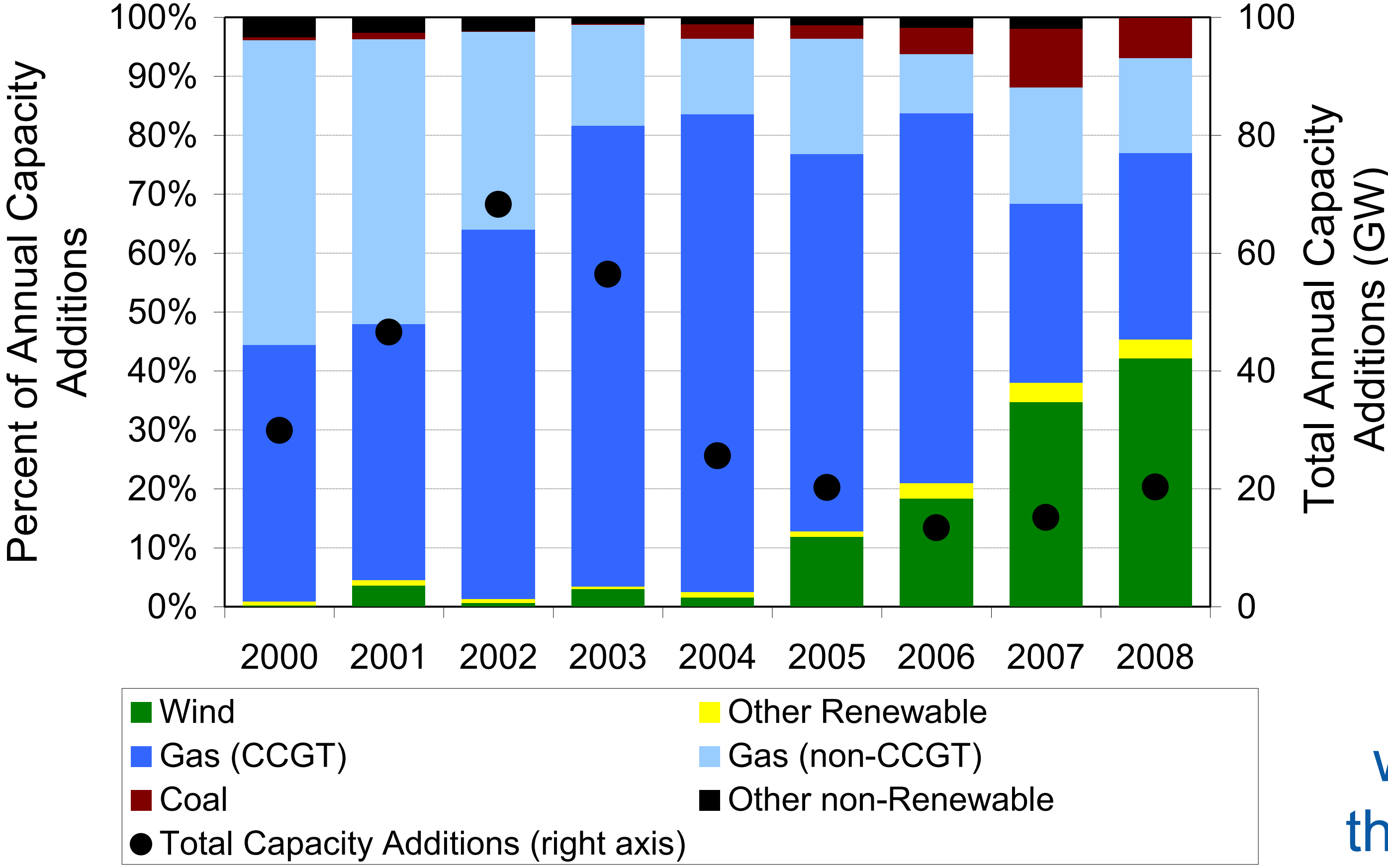
Source: WindPower Monthly

Four Years of Strong Growth:



2008: 8,558 MW Added; $16 billion Investment

Major Source of New Generation Capacity Additions



Source: EIA, Ventyx, AWEA, IREC, Berkeley Lab

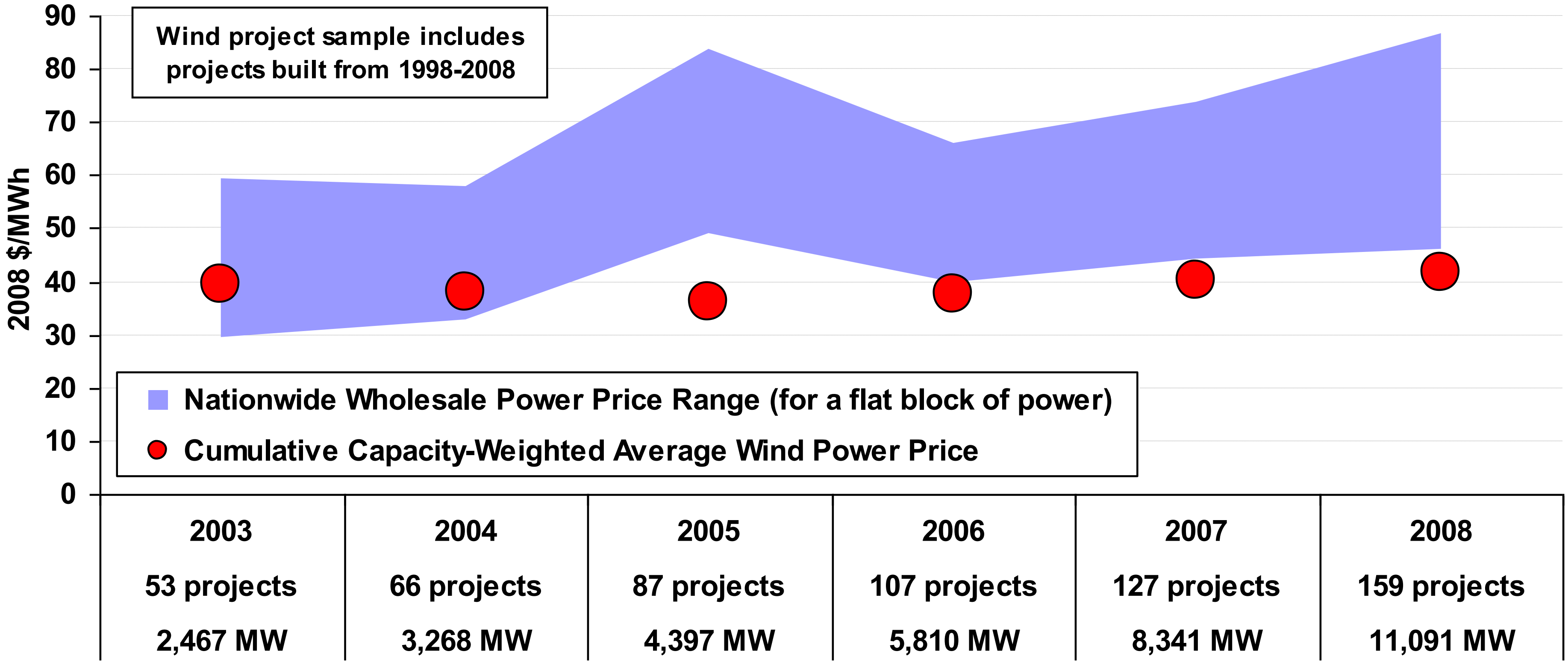
2008: 42%
2007: 35%
2006: 18%
2005: 12%
2000-04: <5%

In 2008 more wind capacity was installed in the U.S. than any other generation technology

Drivers for Wind Power

- Declining Wind Costs
- Fuel Price Uncertainty
- Federal and State Policies
- Economic Development
- Public Support
- Green Power
- Energy Security
- Carbon Risk

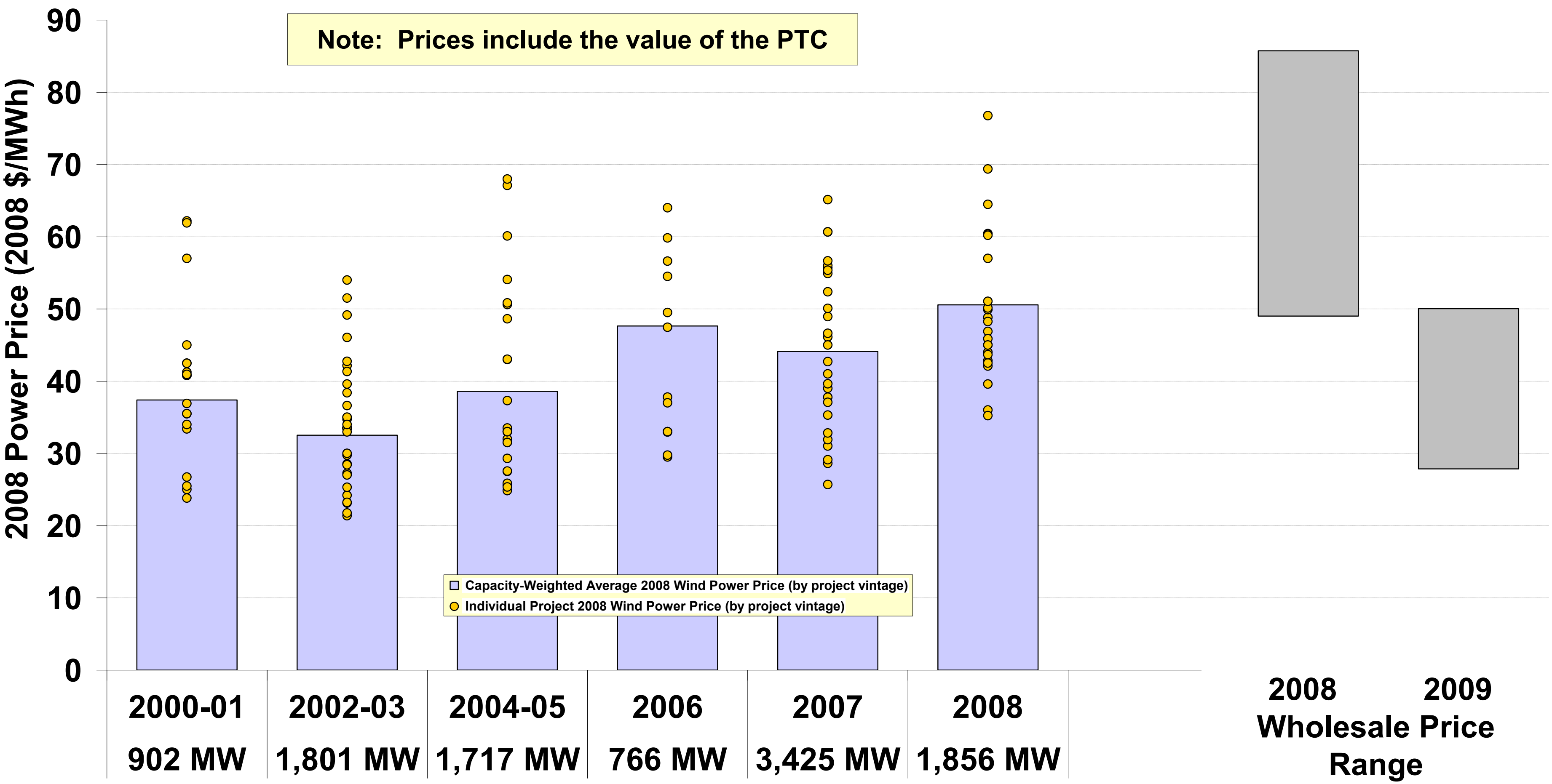
Wind Has Been Competitive with Wholesale Power Prices in Recent Years



Source: FERC 2006 and 2004 "State of the Market" reports, Berkeley Lab database, Ventyx, ICE

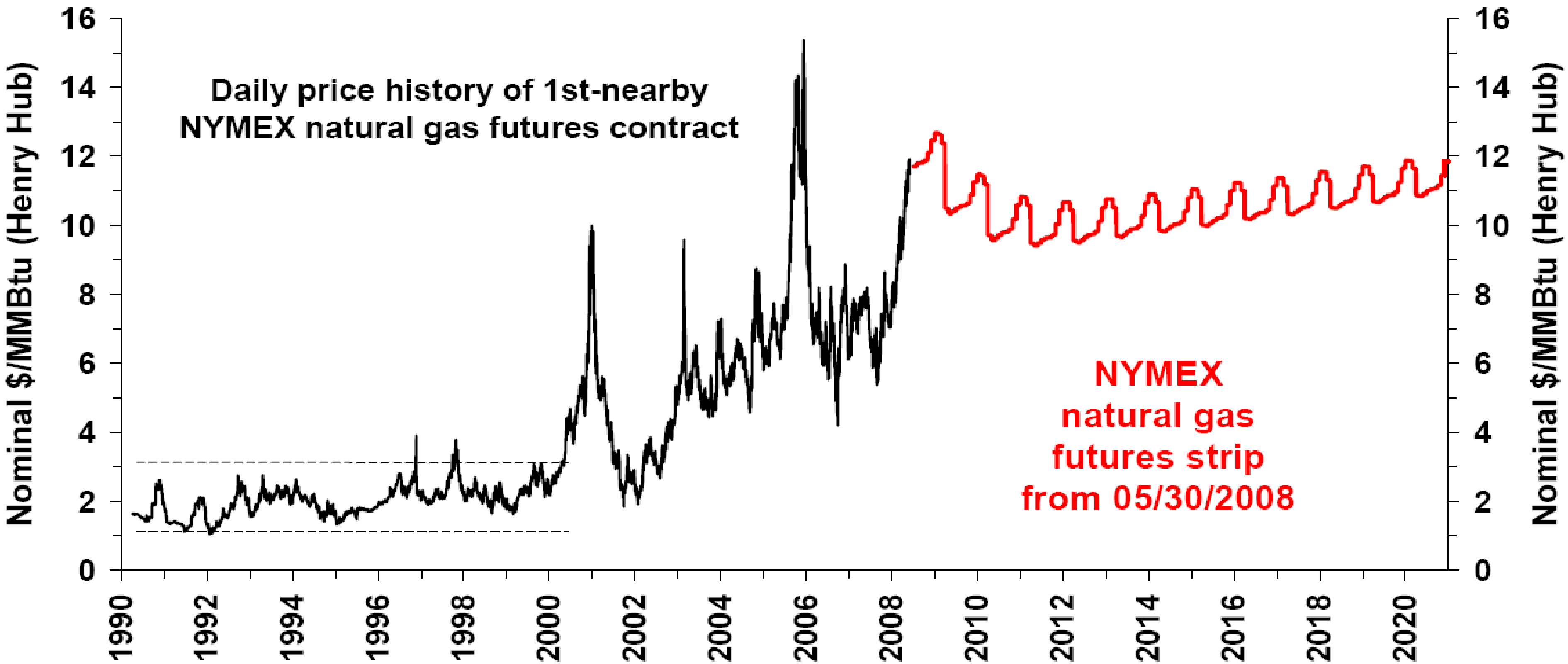
Note: Wholesale price range reflects flat block of power across 23 pricing locations; wind costs represent capacity-weighted average price for wind power for entire sample of projects built from 1998-2008

The Near-Term Wind has Become Somewhat Less Attractive



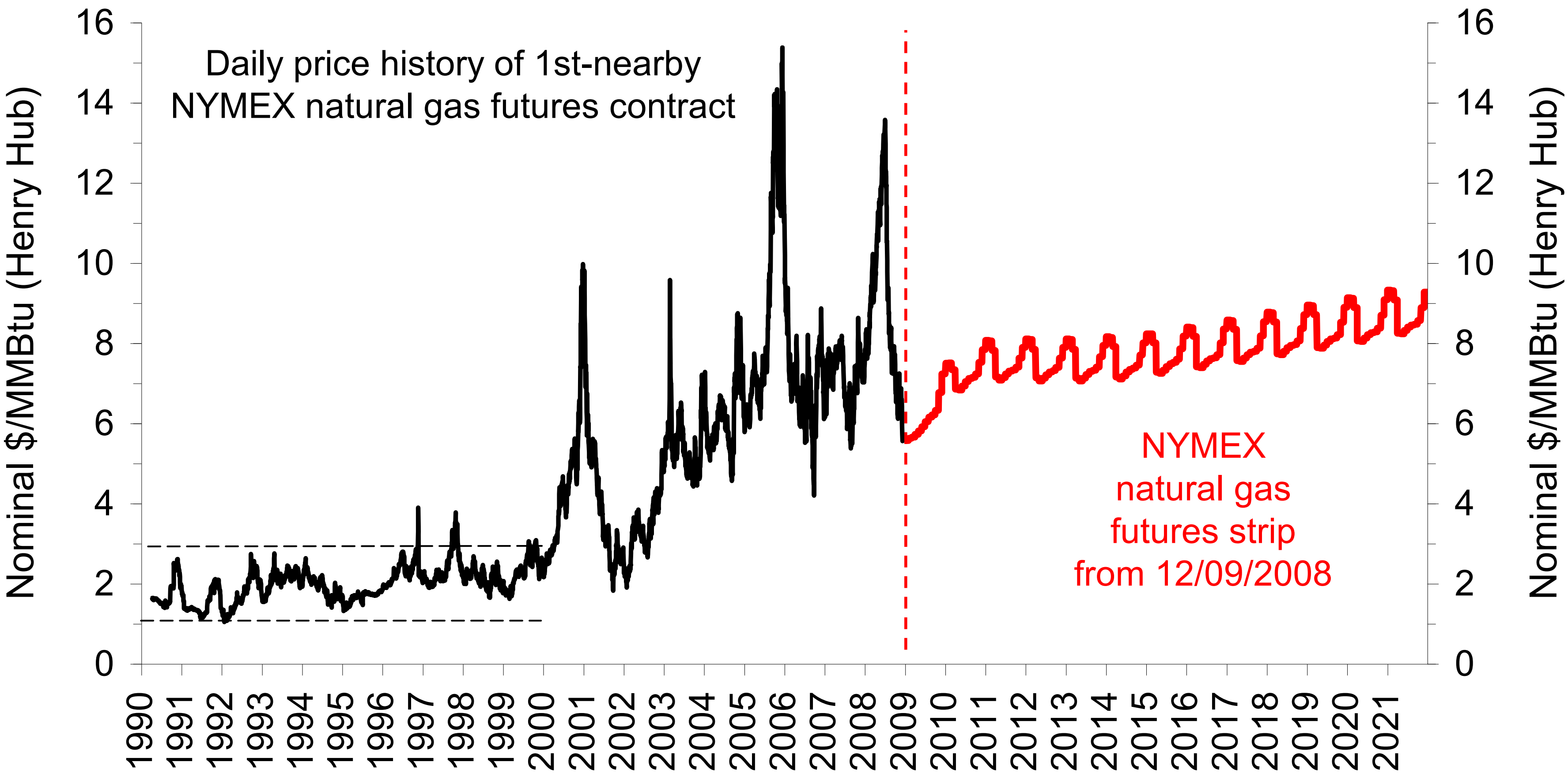
- Wind prices are likely to increase further in 2009 as installed costs will remain high as developers work through turbines ordered at peak prices, and given higher equity yields.
- Wholesale price's are also likely to increase as the economic depression reverses course

Natural Gas Price Variability



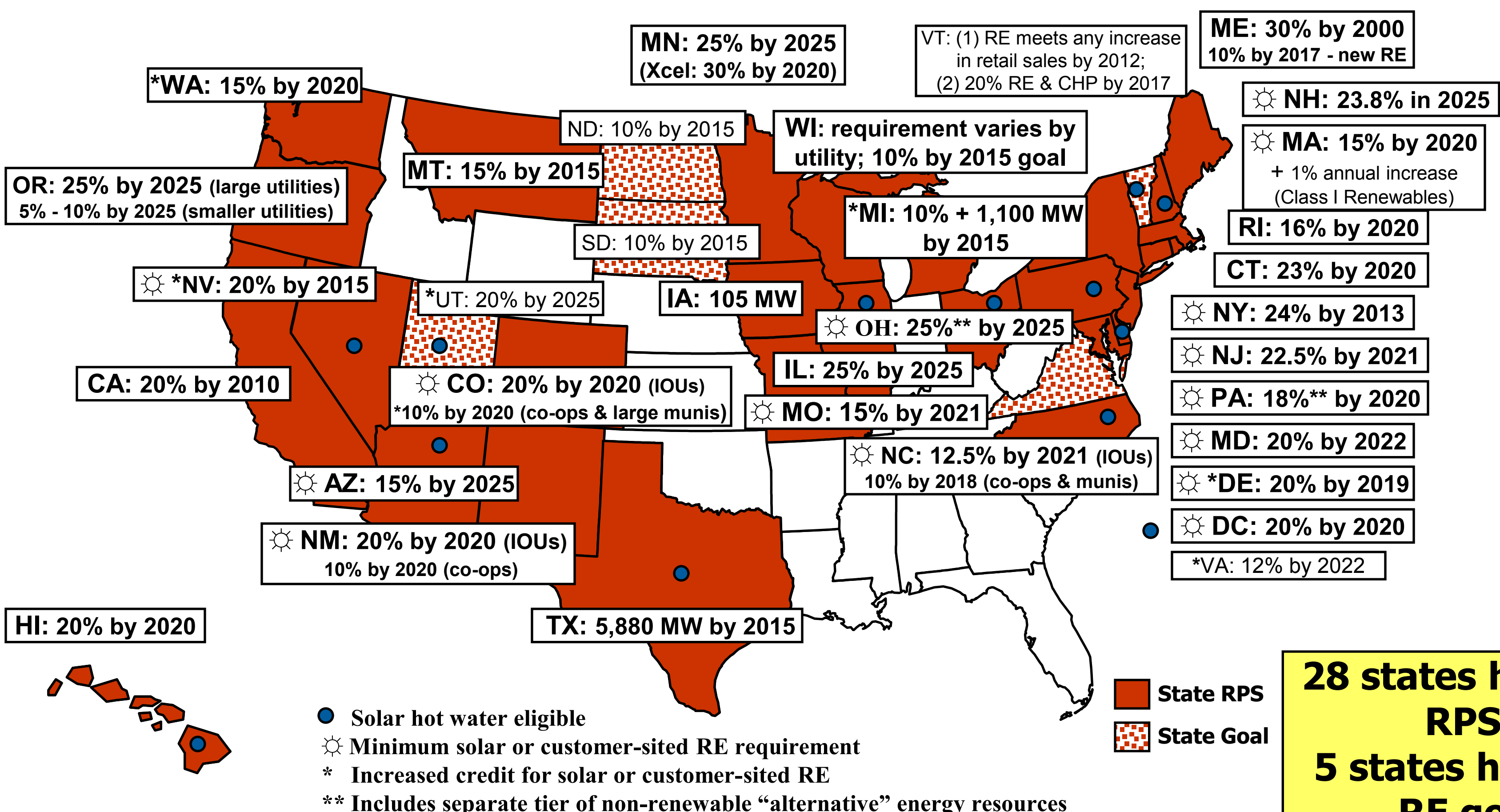
Source: LBNL

Natural Gas – Historic Prices



Source: LBNL

Renewables Portfolio Standards



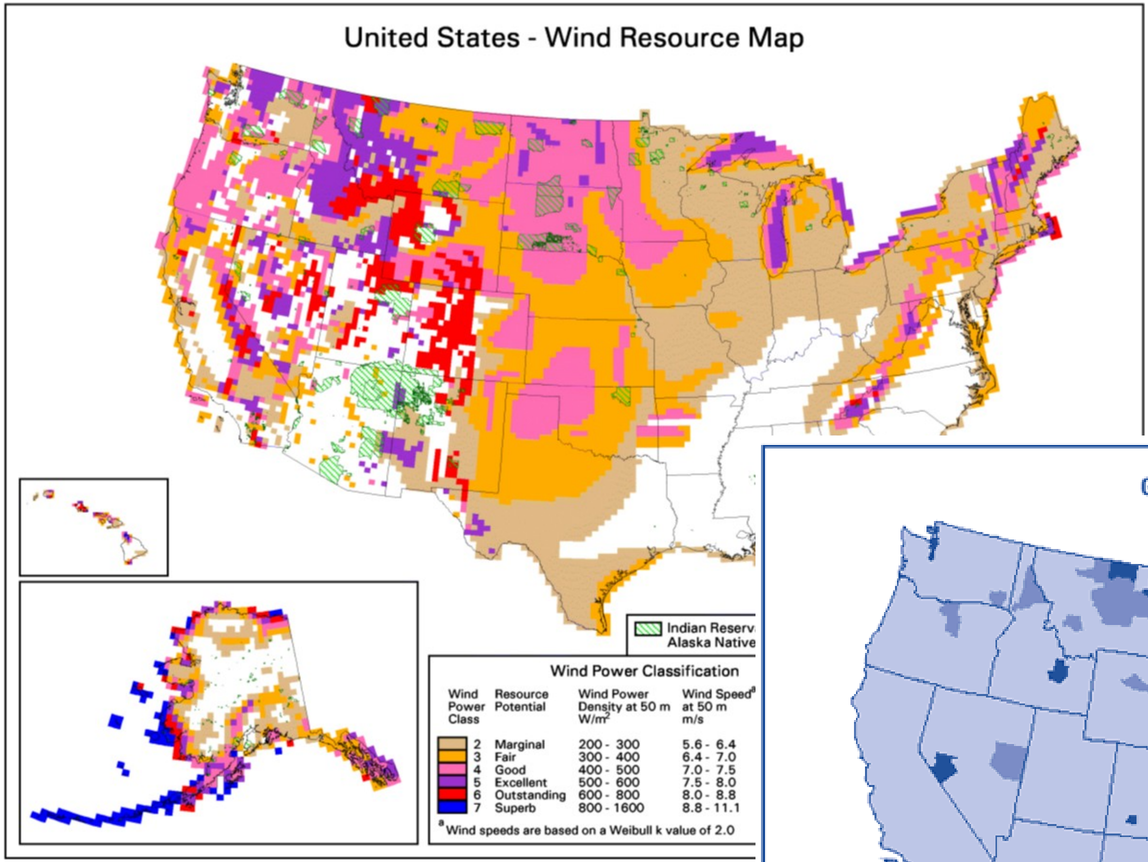
28 states have an RPS;
5 states have an RE goal

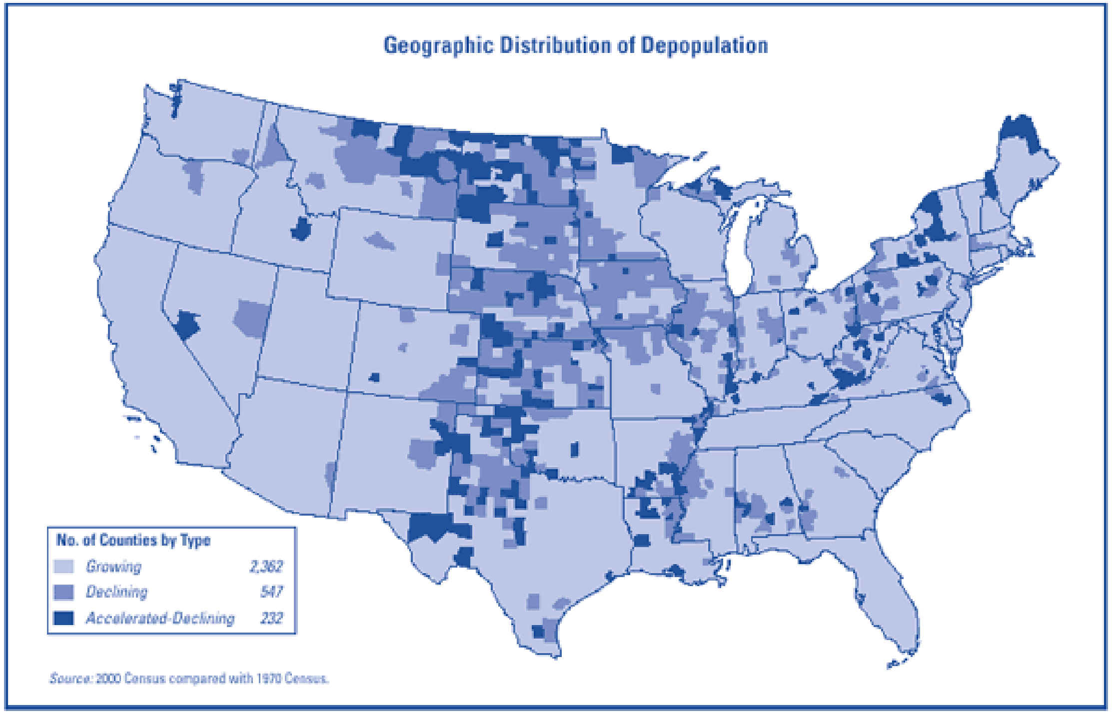
DSIRE: www.dsireusa.org
January 2009

Federal Goals:

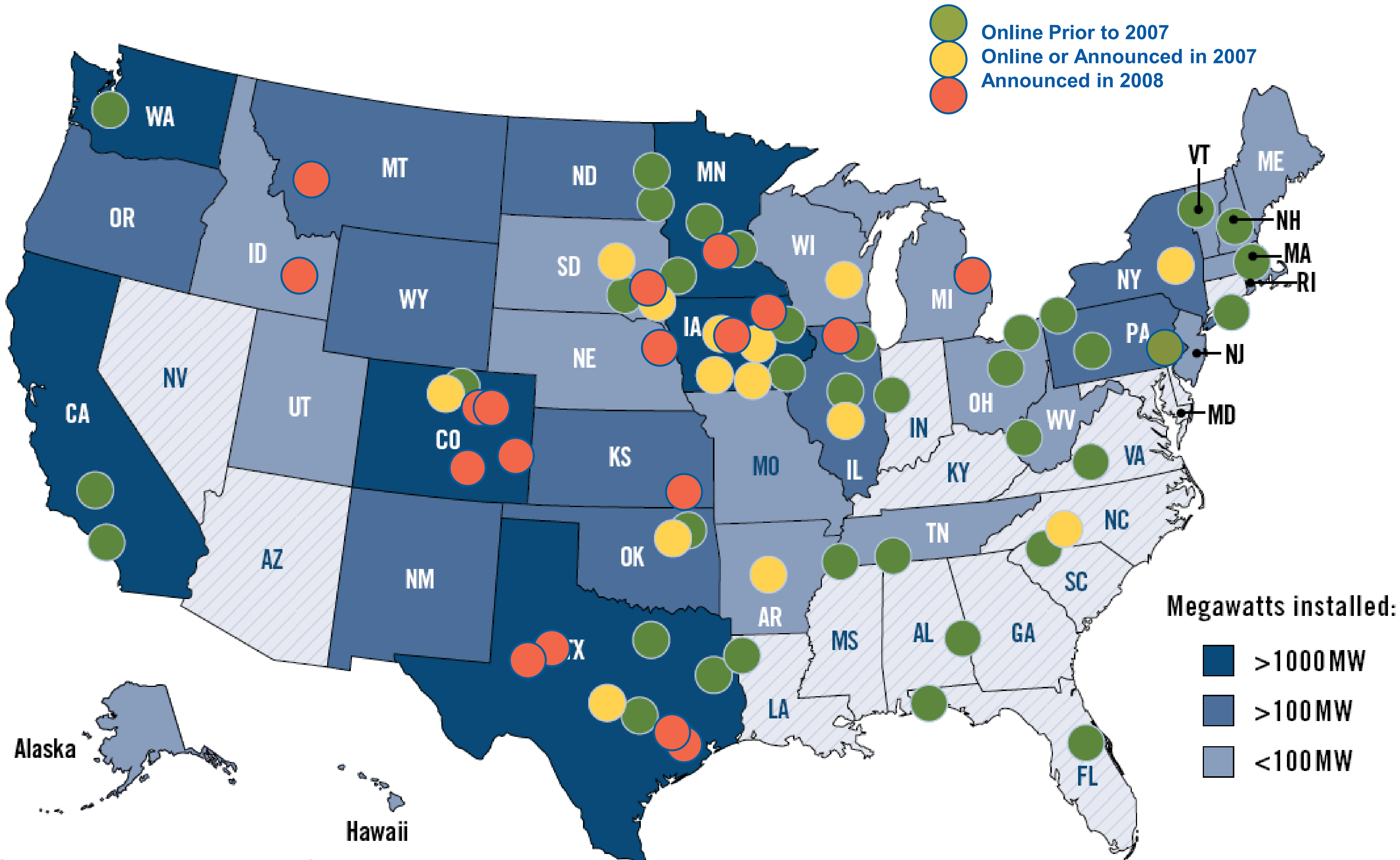
- EPAct 2005: 3% by FY09; 5% by FY12 and 7.5% by FY13
- Executive Order 13423: At least 50% new RE, on-site if possible

Windy Rural Areas Need Economic Development





Soaring Demand Spurs Expansion of U.S. Wind Turbine Manufacturing

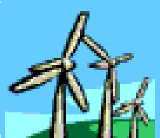


Source: AWEA, updated Sept 2008

Colorado – Economic Impacts

from 1000 MW of new wind development

Wind energy's economic "ripple effect"



Direct Impacts

Payments to Landowners:
- $2.5 Million/yr

Local Property Tax Revenue:
- $4.6 Million/yr

Construction Phase:
- 912 new jobs
- $133.6 M to local economies

Operational Phase:
- 181 new long-term jobs
- $19.3 M/yr to local economies

Indirect & Induced Impacts

Construction Phase:
- 807 new jobs
- $92.7 M to local economies

Operational Phase:
- 129 local jobs
- $15.6 M/yr to local economies

Totals
(construction + 20yrs)

Total economic benefit = $924.3 million
New local jobs during construction = 1,719
New local long-term jobs = 310

All jobs rounded to the nearest 50 jobs; All values greater than $10 million are rounded to the nearest million

Construction Phase = 1-2 years
Operational Phase = 20+ years

Environmental Benefits

No SOx or NOx

No particulates

No mercury

No CO2

No water

Energy-Water Nexus

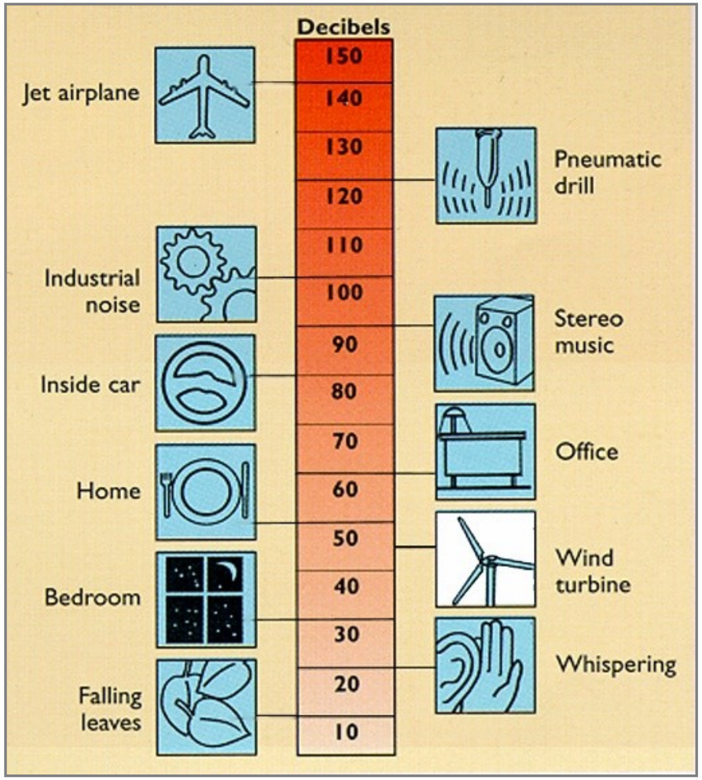
Other Considerations

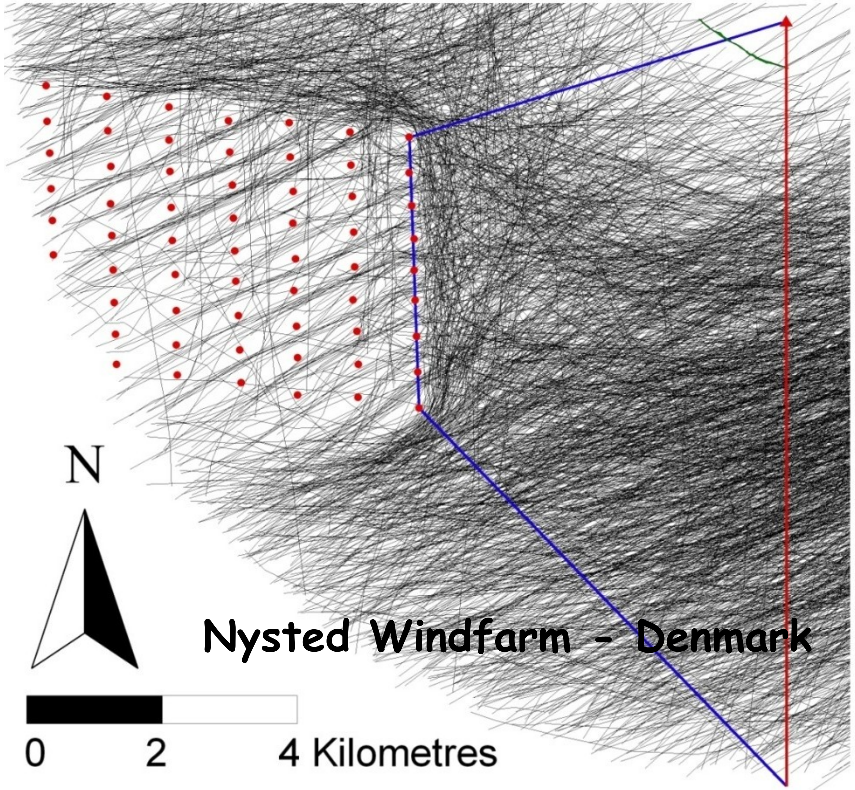
- Policy
- Siting
- Transmission
- External Conditions
- Intermittency

Siting Issues

Visual Impact & Land Ownership

Noise



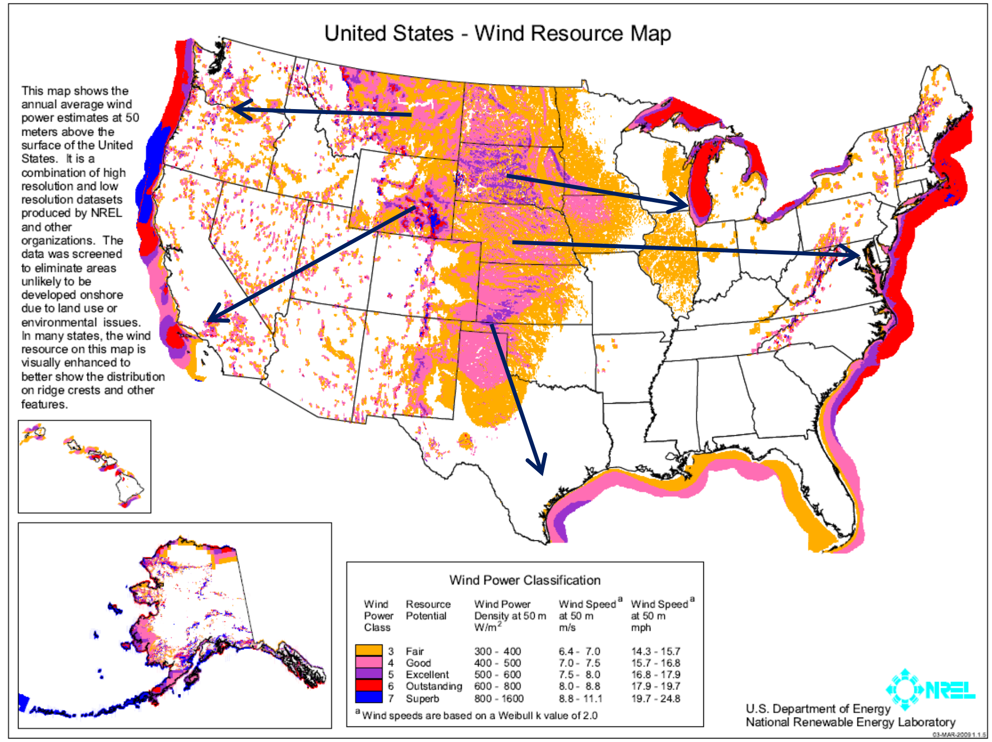


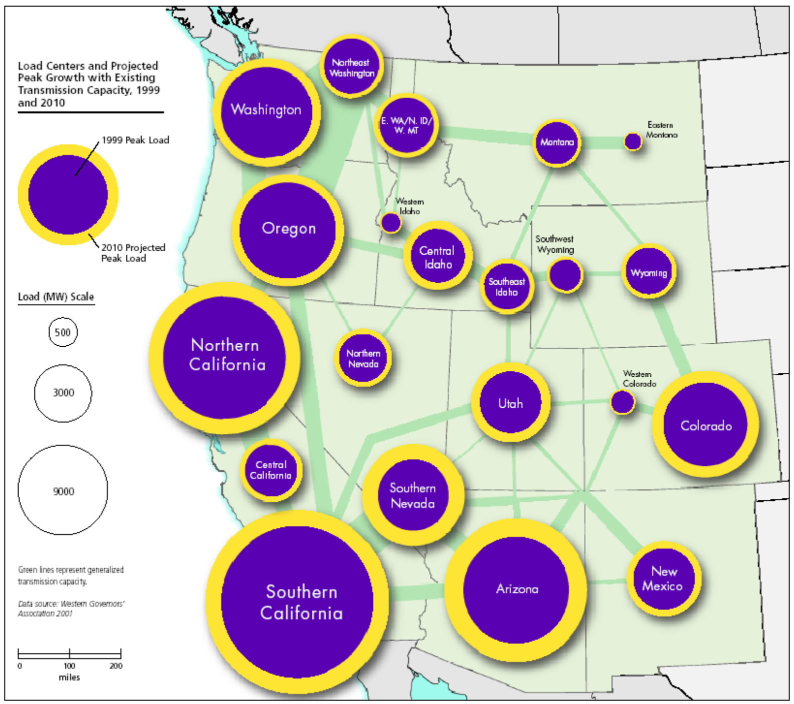
Avian and other wildlife:

- Over 200 projects, Three problem sites.
- Biggest avian problem was in the Altamont Pass.
- Managed by careful site selection.

Transmission

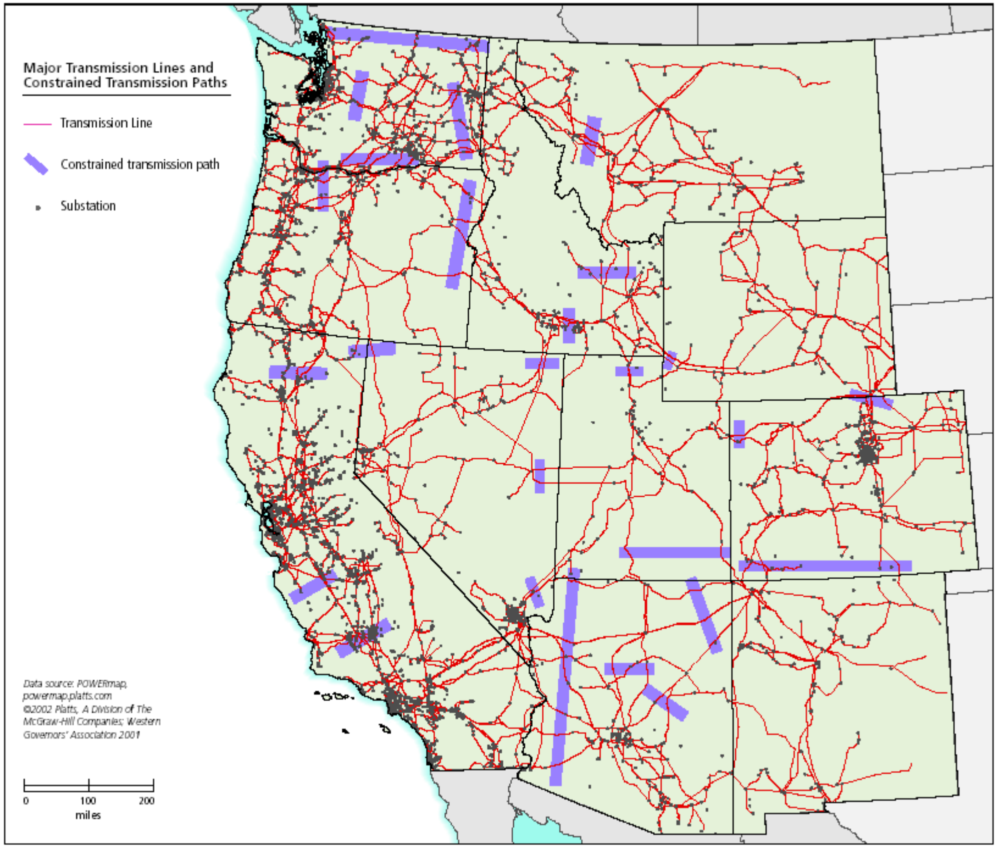
- Limitations
- Grid Access
- System studies
- Allocation of available capacity
- Scheduling and costs for usage



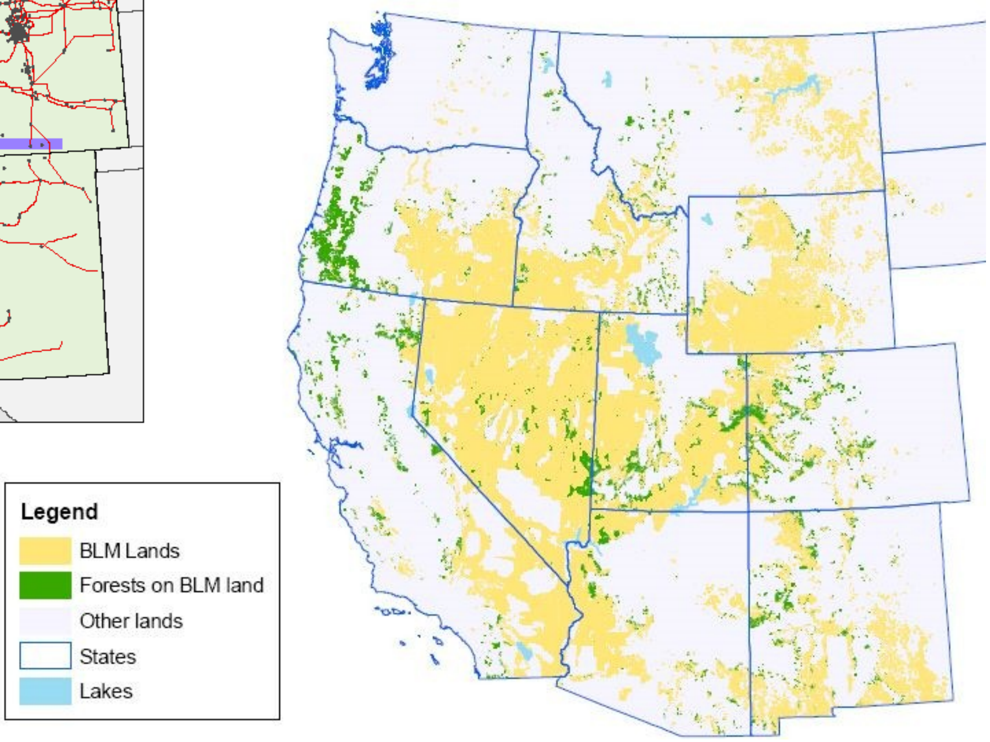


A great deal of discussion of large scale transmission to take energy from the high resource areas to the loads – but these projects will take years

BLM Role in Expanded Wind Development



BLM lands will need to play a key near term role in allowing the development of wind in the west if we are to meet growing energy needs in the face of a constrained carbon future



Additional Considerations

Policy

- Encourage economic development and use of local resources
- facilitate “green” markets
- Federal, state and local incentives such as the Production Tax Credit (PTC) and Renewable Portfolio Standards (RPS

Remote Systems

- Amount of energy from wind
- Control of system voltage and frequency
- Use of excess wind energy

External Conditions

- Lightning
- Extreme Winds
- Corrosion
- Extreme temperatures

Intermittency

- Operational Impacts (ancillary services including voltage/VAR control, load following, etc.
- 10-20% of system capacity is reasonable

Wind Applications

Distributed

Homes
Farms
Small business
Remote Applications
Schools

Wind Farms

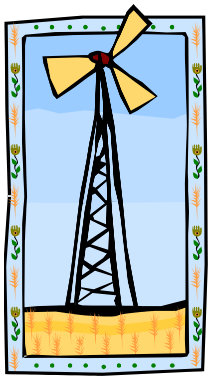
Large Central Station Power

Community Projects

Large businesses
Municipal loads
Schools
Federal Loads

Critical Aspects of Wind Energy

$$P = 0.5\ \rho\ Cp\ v^3\ A_S$$

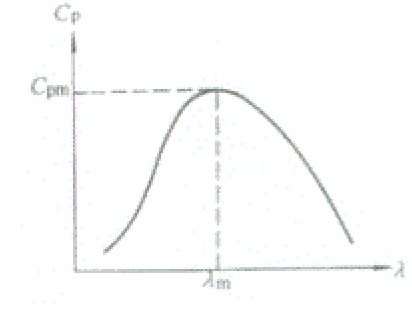


V^3: Doubling of the wind speed results in an 8 fold increase in power

ρ: High density air results in more power (altitude and temperature)

A_s: A slight increase in blade length, increases the area greatly

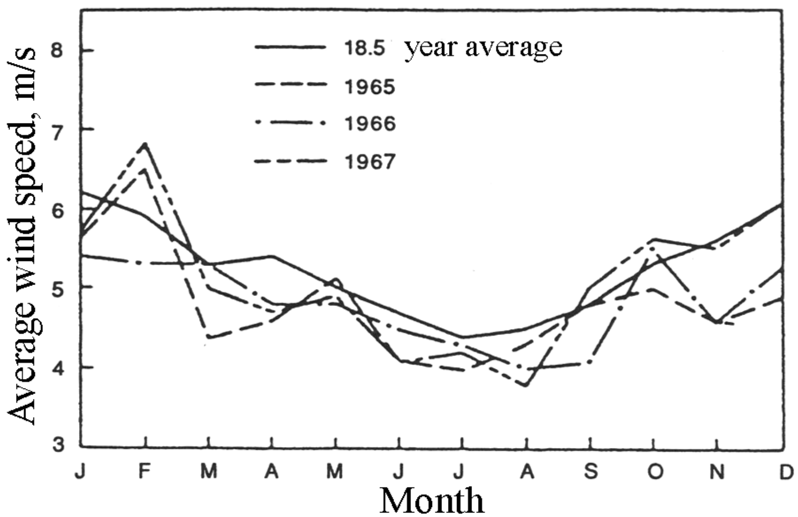
Cp: Different types of wind turbines have different maximum theoretical efficiencies (Betz limit ≈0.593) but usually between .4 and .5



Basic Wind Turbines

- Understanding the wind resource at your location is critical to understanding the potential for using wind energy
  – Wind speed
  – Wind direction
  – Wind speed change with height
- Lift and Drag – The different types of wind turbines
- Power Curves – The performance of wind turbines
- Power Availability - Power your can get from the wind
- Terms – What do you need to know about the wind industry

Wind Speed

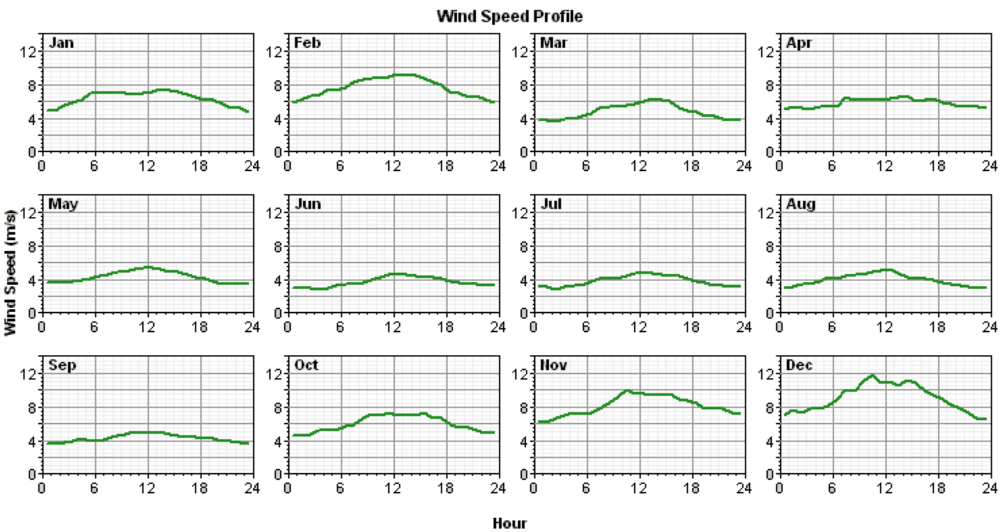


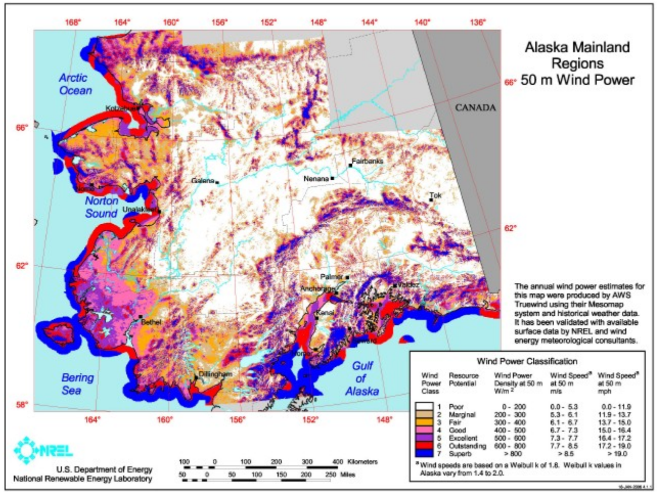
Measured in m/s or mph

Varies by the second, hourly, daily, seasonally and year to year

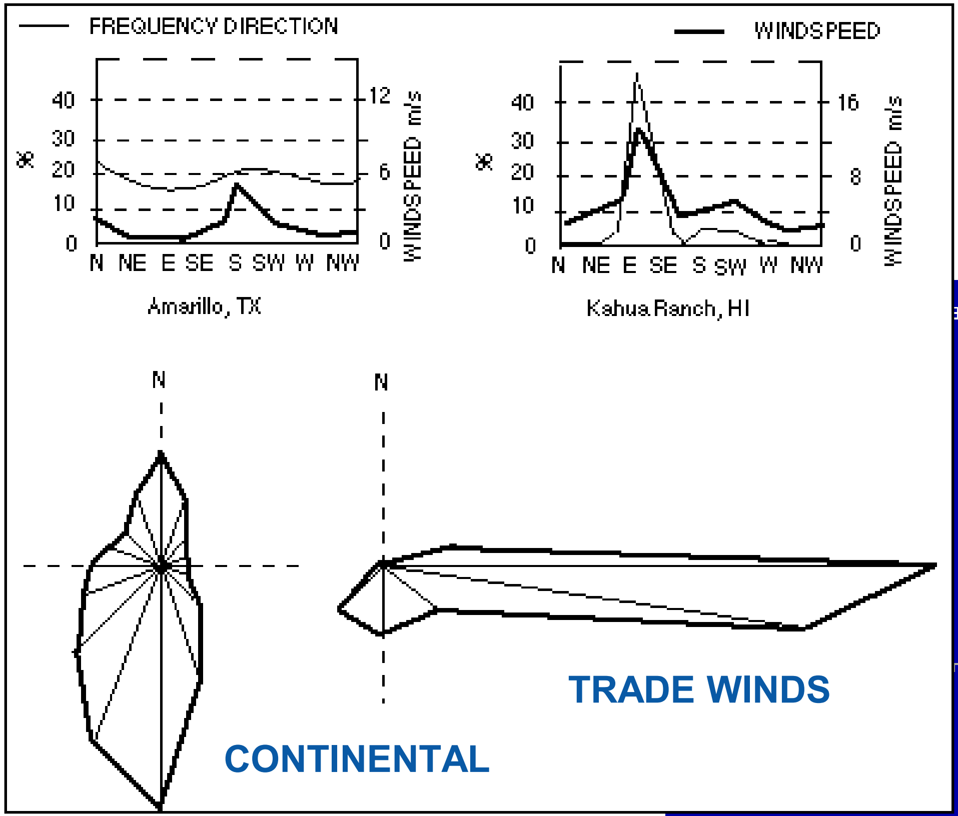
Usually has patterns

- Diurnal - it always blows in the morning
- Seasonal – The winter winds are stronger
- Characteristics – Winds from the sea are always stronger and are storm driven.



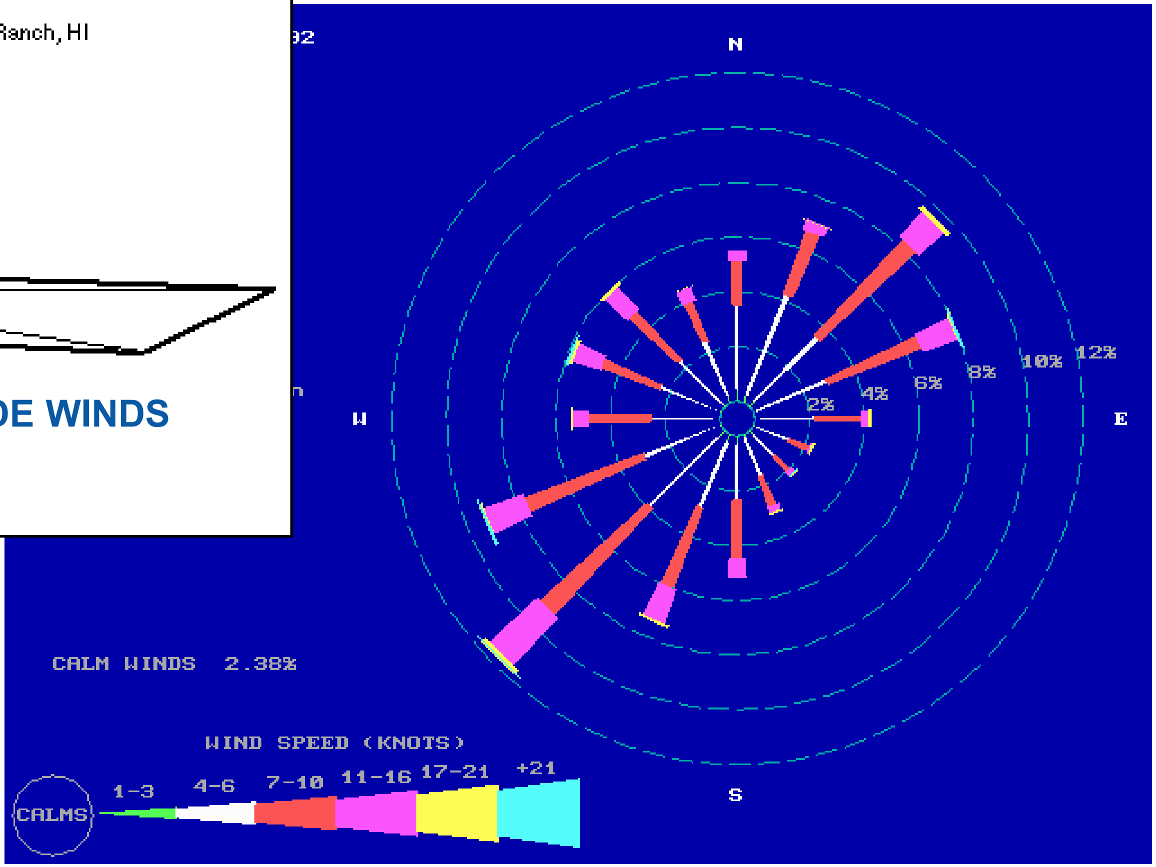


Wind Direction



Wind Rose

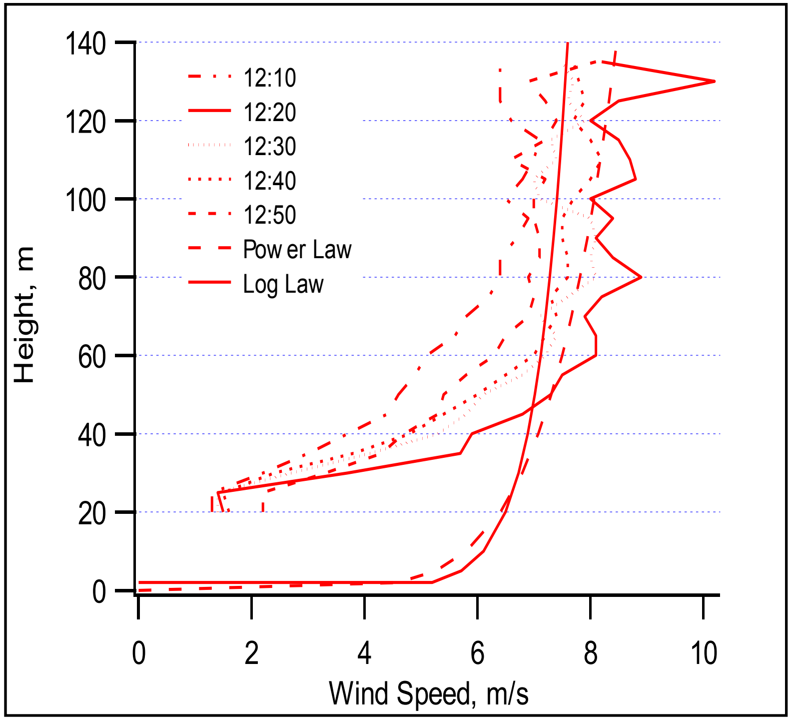
Wind Speed Rose



Can also have a wind direction change intensity – similar to turbulence

Wind Speed Increases with Height

- Because of friction with the earth, air closer to the surface moves more slowly
- The farther we get away from the earth (increase in altitude) the higher the wind speed gets until it is no longer effected by the earths surface



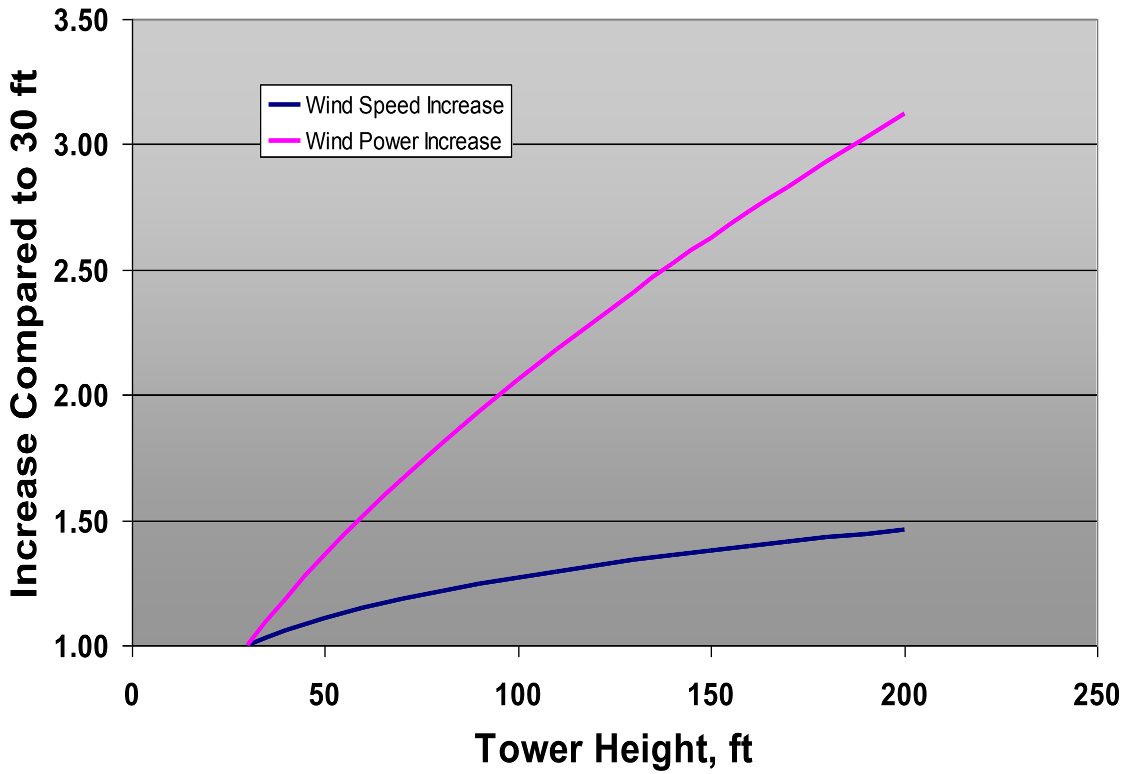
$$V_N = V_O \left[\frac{h_N}{h_O} \right]^N$$

Terrain	Power Law Exponent
Water or ice	0.1
Low grass or steppe	0.14
Rural with obstacles	0.2
Suburb and woodlands	0.25

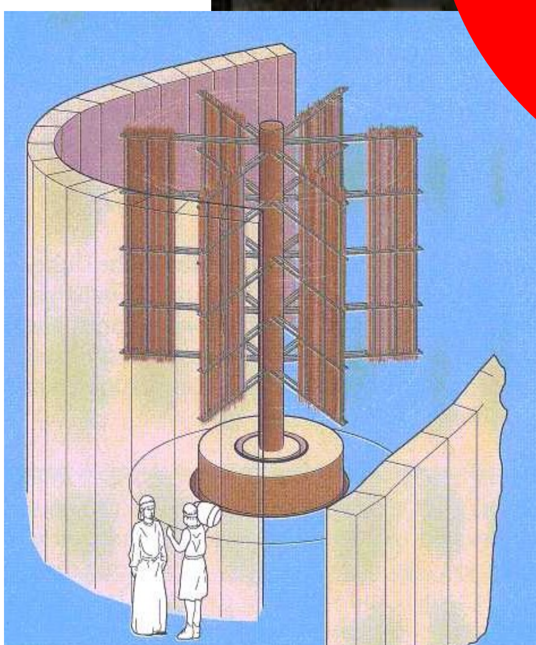
Source: Paul Gipe, Wind Energy Comes of Age, John Wiley and Sons Inc, 1995, pp 536.

V_N: Wind speed at new height,
V_O: Wind speed at original height,
h_N: New height,
h_O: Original height,
N: Power law exponent.

Height Impacts on Power



Classic Drag Devices



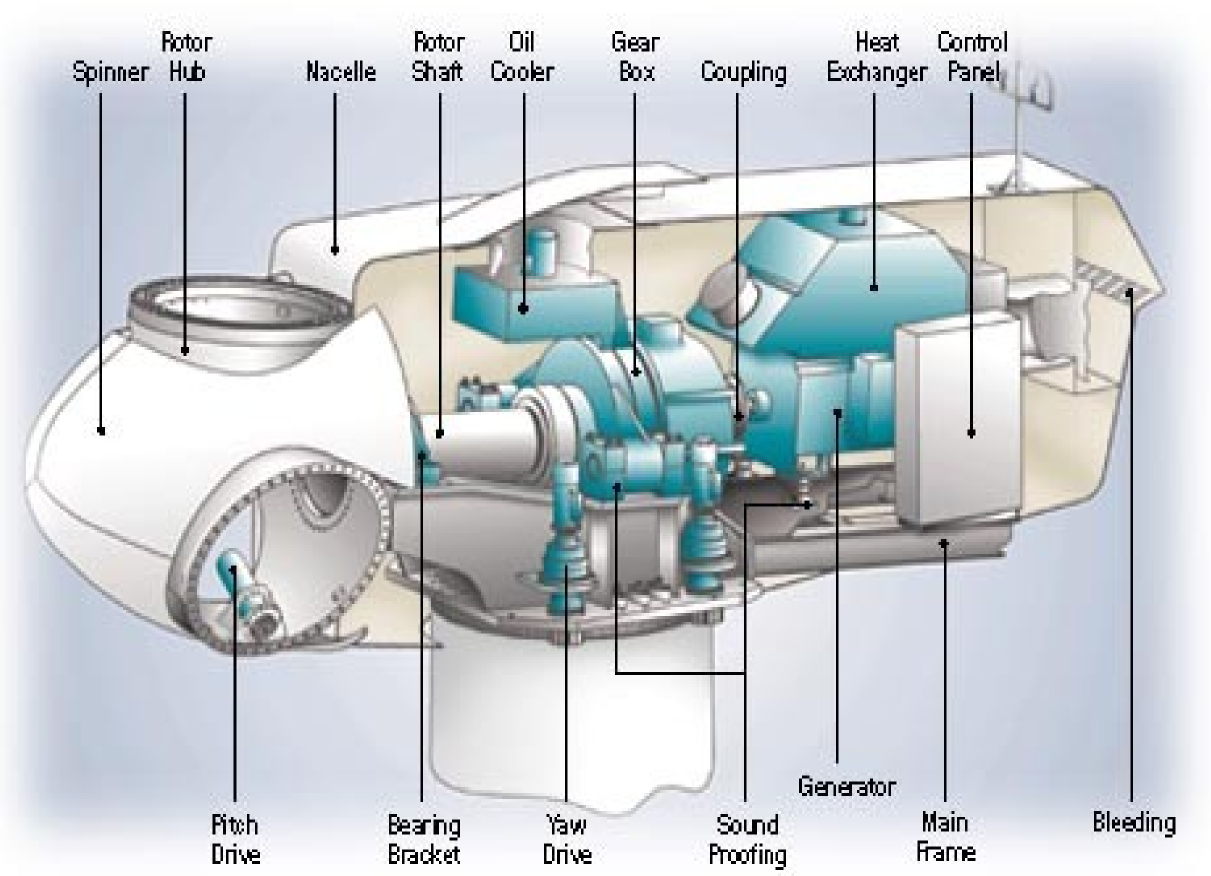
Use aerodynamic drag to produce power. Typically have high torque and work well in low wind speeds, but not at high wind speeds

Lift Wind Turbines

Types of Lift Turbines

HAWT VAWT

Large Wind Turbines



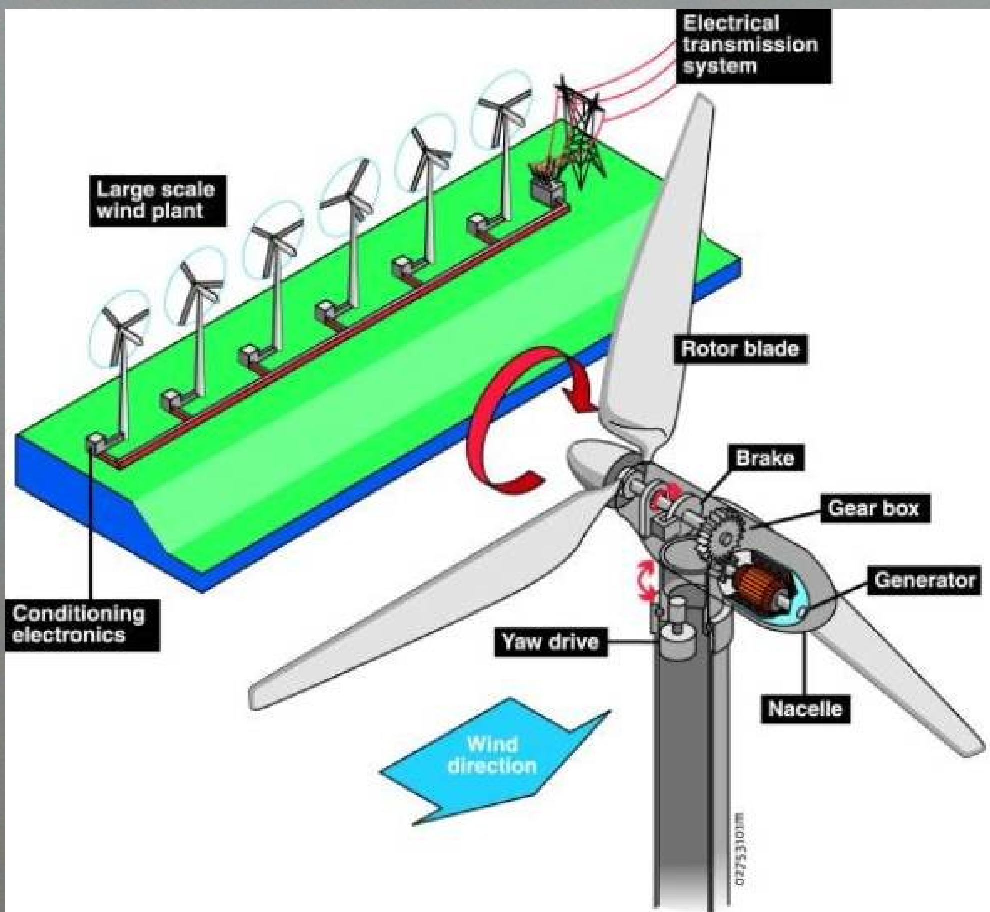
Generator/gearbox:
- Induction
- variable speed
- Direct Drive

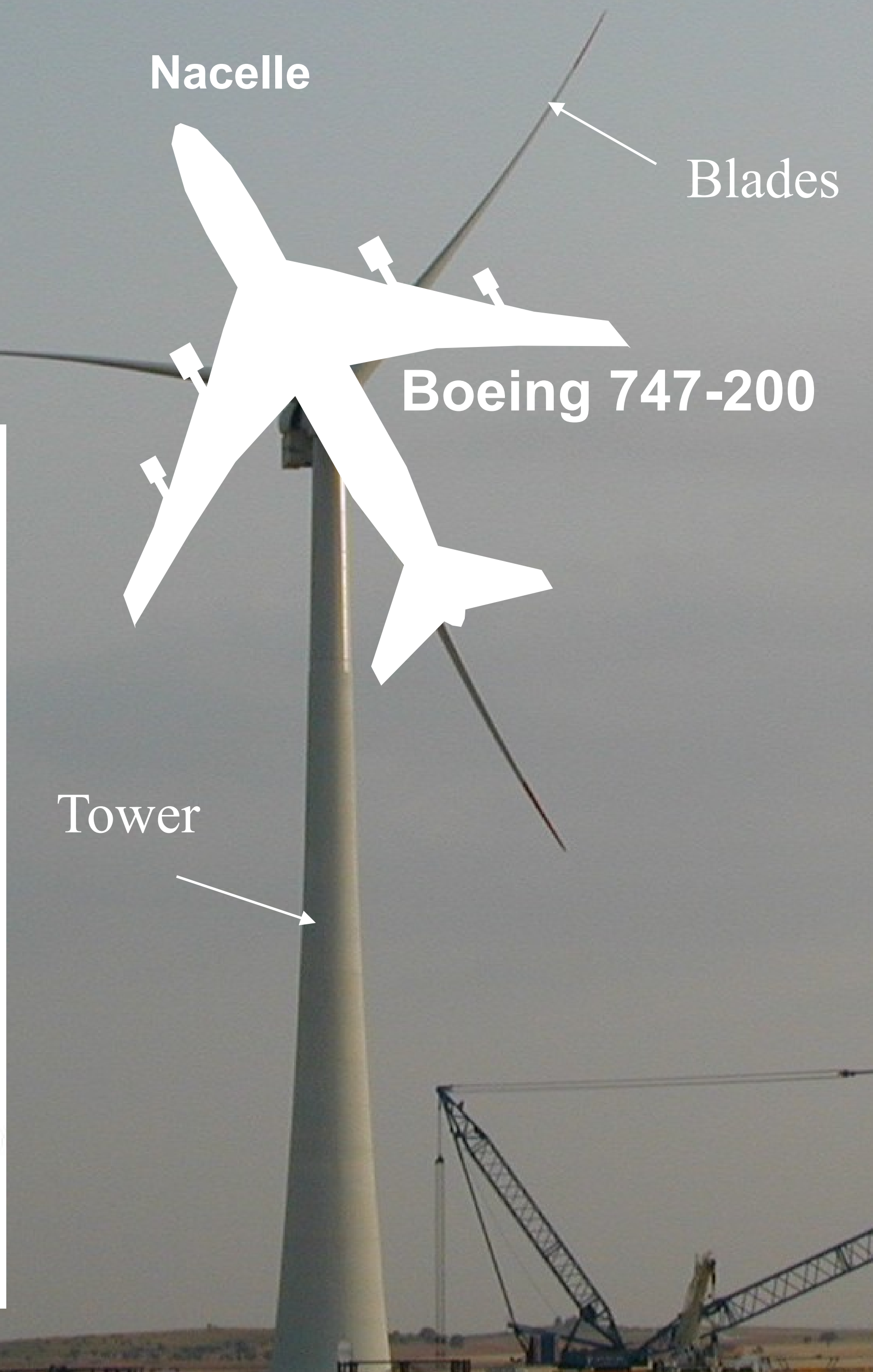
Control:
- Stall (passive)
- Active pitch
- Power control

Active Yaw control

Connected at the transmission or distribution level

Parts of a Wind Turbine Power Plant





Characteristics of Large WTG

Power Types

- Induction (Constant speed)
- Permanent Magnet (Variable speed) using power electronics

Control:

- Stall (passive)
- Active pitch
- Power control

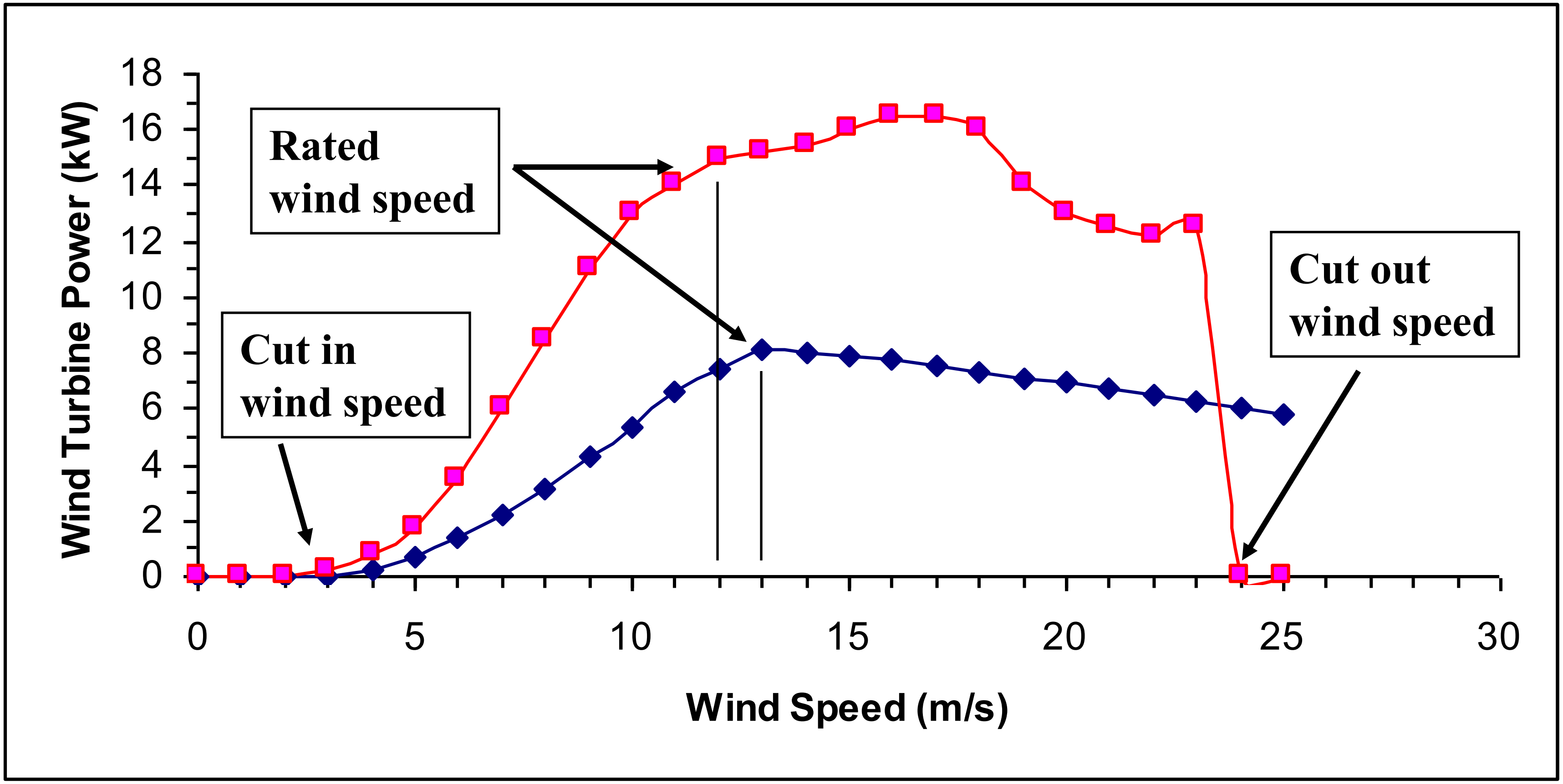
Active Yaw control

Connected at the transmission or distribution level

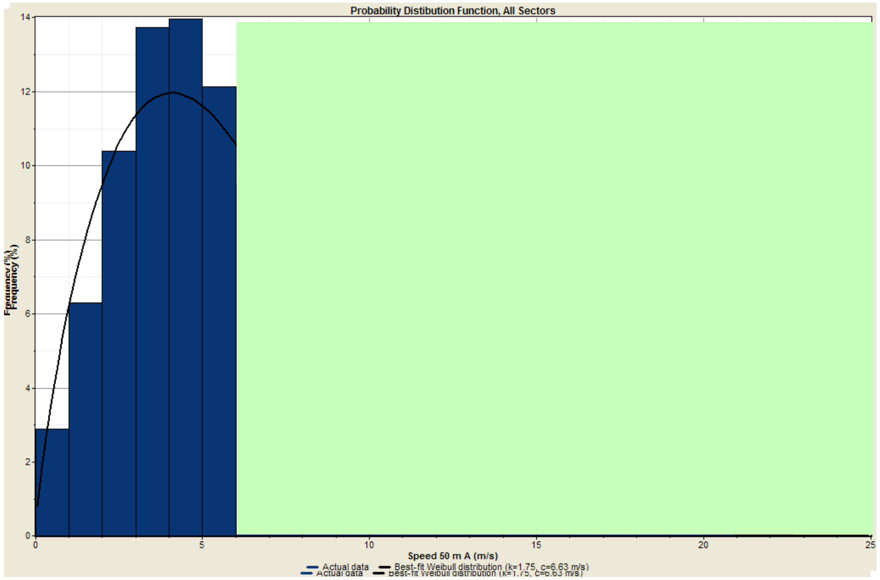
Remote monitoring standard

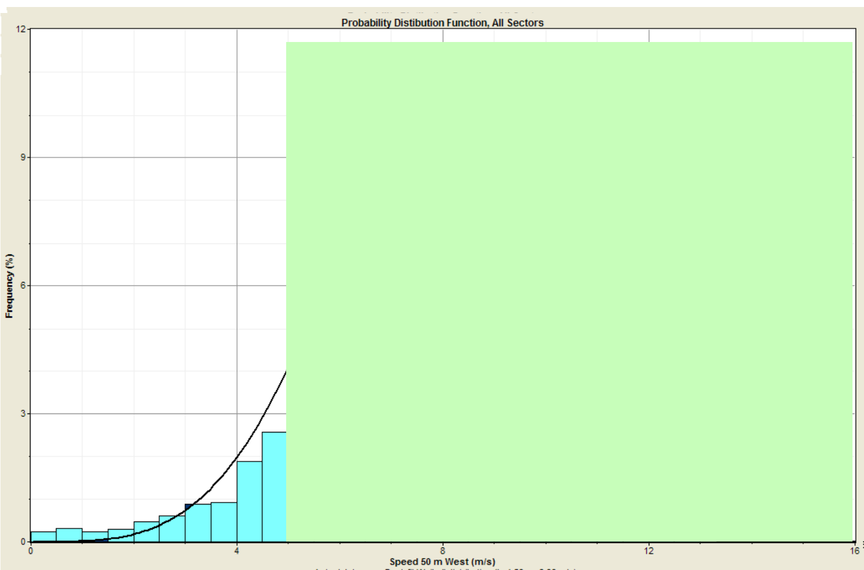
Dedicated maintenance staff for large projects

WTG Power Curve



Frequency Distribution





Wind frequency distribution:

Inform us on how many hours per year the wind blows at each wind speed

Top graph – Very few hours that the turbine will be operating

Bottom graph – Many more hours a year that the turbine will be operating

Important Terms

Cut in wind speed: The wind speed that the turbine starts producing power (may be different than the speed at which the turbine starts spinning)

Rated Wind Speed: The wind speed at which the turbine is producing “rated power” – though “rated power” is defined by the manufacture

Cut out wind speed: The wind speed at which the turbine stops producing power

Shut down wind speed: The wind speed at which the turbine stops to prevent damage

Survival wind speed: Wind speed that the turbine is designed to withstand without falling over

Availability: The amount of time that the wind turbine is available to produce power (Maintenance parameter)

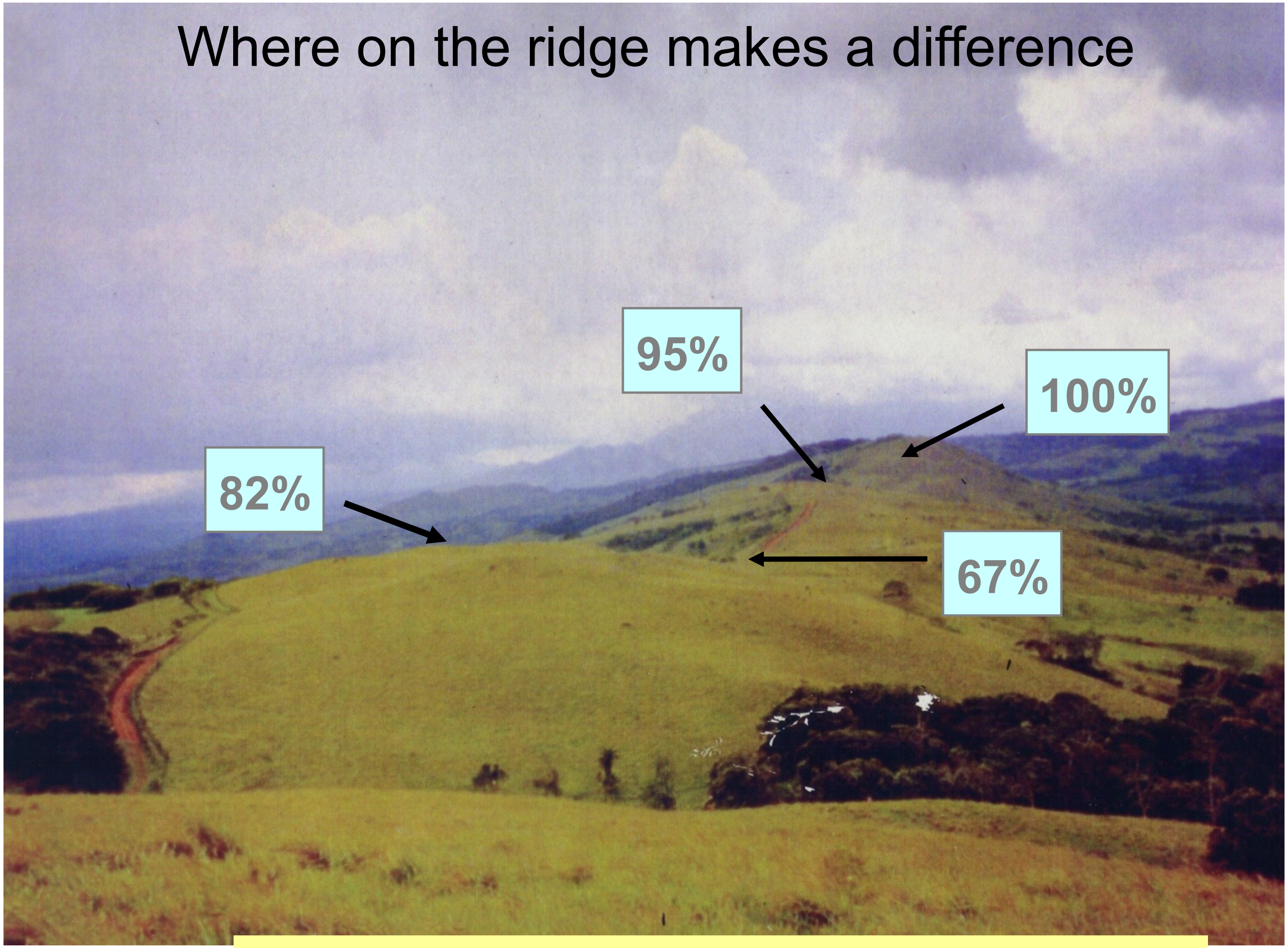
Capacity Factor: The annual energy production of a wind turbine divided by the theoretical production if it ran at full rated power all of the time (Resource parameter)

- The stronger the resource the higher the Capacity Factor
- Usually reported monthly or yearly
- 25-40% is typical, up to 60% has been reported
- Reason for the “only works 1/3 of the time” quote.

Wind Turbine Siting Matters

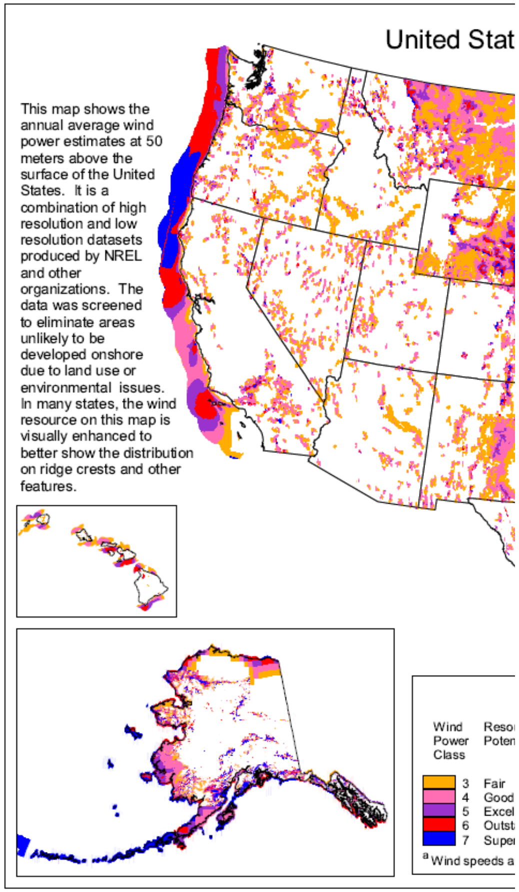
- Wind varies year-to-year, site-to-site.
- Developers want sites that maximize the wind resource, minimize risk
- Thorough assessment helps to minimize, <u>not eliminate</u>, the risk
- Uneven heating of the earth surface causes wind
  - seasonal change in vegetation can affect the wind seasonally – snow cover vs. dark green foliage vs. brown foliage vs. no foliage
  - terrain features like large valley can have upslope winds in morning and downslope winds in afternoon
  - drought or forest fire can impact winds generated from surface conditions
  - other earth system features impact wind irregularly – El Nino
- Terrain impacts wind
  - canyons, terrain undulations, trees/forests, buildings can contribute to turbulence which dissipates the wind

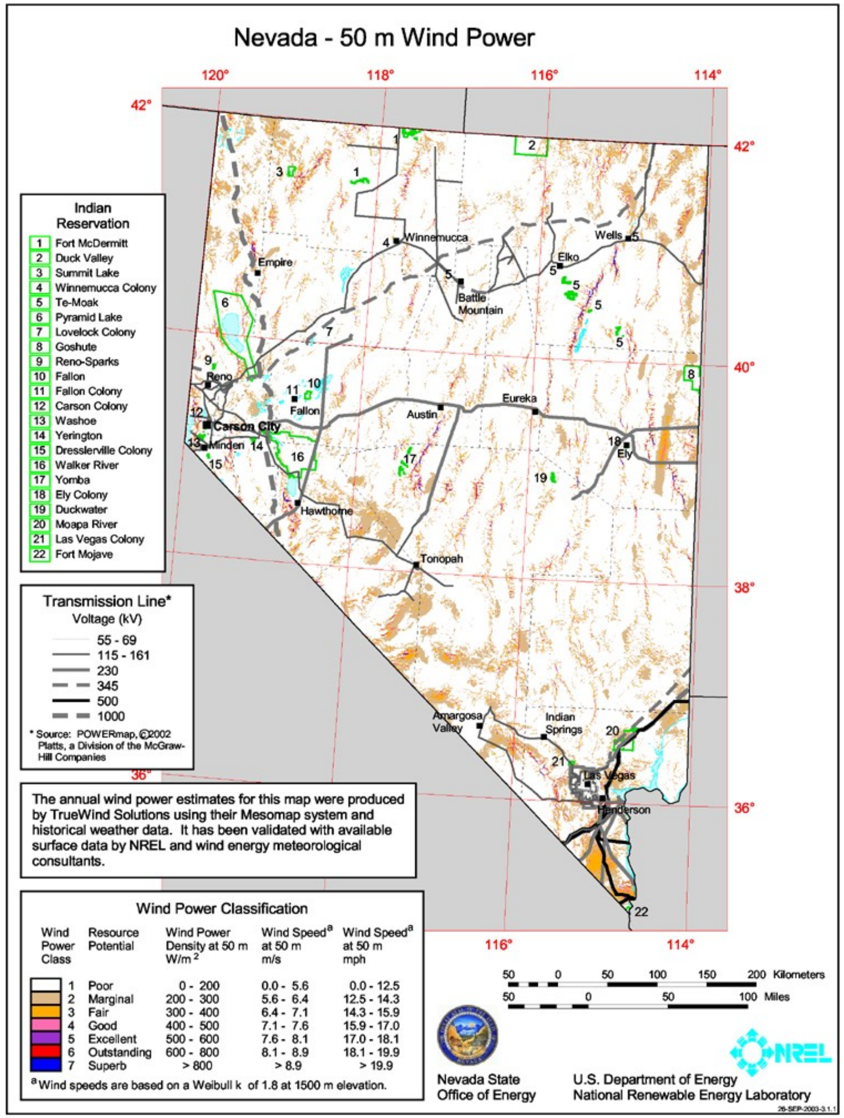
Siting Makes a Difference



Slide credit: Global Energy Concepts, Inc

Wind in the West is Very Area Specific





Wind in the west is driven primarily by topography

Access to ridges and mesa tops are critical to economic wind production

Class 3 vs Class 6 Wind Site

Class 3 – at 50m – wind speeds 6.4 – 7.0 m/s
Mean wind speed of 6.7 m/s used for calcs

BASE CASE - CLASS 3 WIND		
Annual Energy	2,085,849	kWh/yr
Annual Revenue/turbine	$125,151	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$25,030,184	$/yr/farm

What is means to BLM:
Class 3 site = 150 turbines
Class 6 sites = 58 turbines

Need 159% more wind turbines at Class 3 site

Class 6 – at 50m – wind speeds 8.0 – 8.8 m/s
Mean wind speed of 8.4 used for calcs

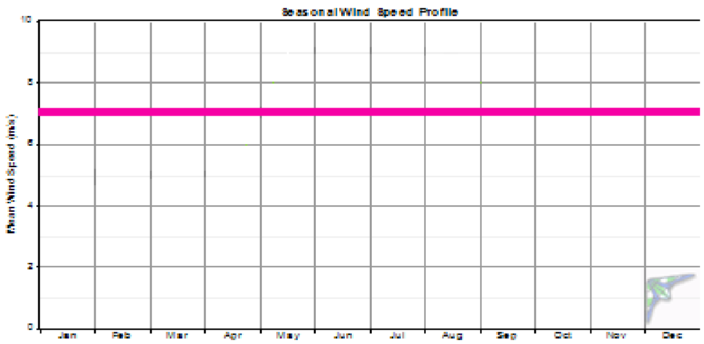
CLASS 6 WIND		
Annual Energy	5,025,063	kWh/yr
Annual Revenue/turbine	$301,504	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$60,300,755	$/yr/turb
Increase in Rev/Yr	$37,763,470	$/yr/farm
Energy & Rev Increase	167.6%	

The revenue "increase" at this Class 6 site is greater than "annual revenue" at Class 3 site !

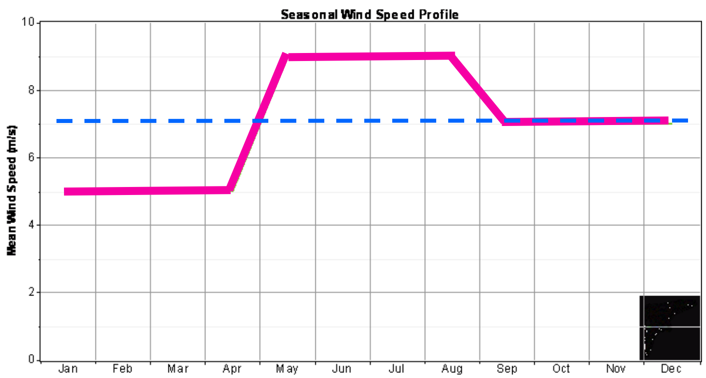
Importance of Wind Resource Assessment

Mean Annual Wind Speed = 7 m/s

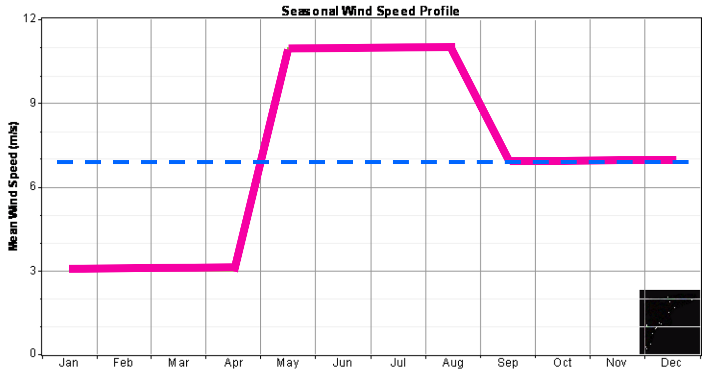
Steady 7 m/s



1/3 of year at 5 m/s
1/3 of year at 7 m/s
1/3 of year at 9 m/s

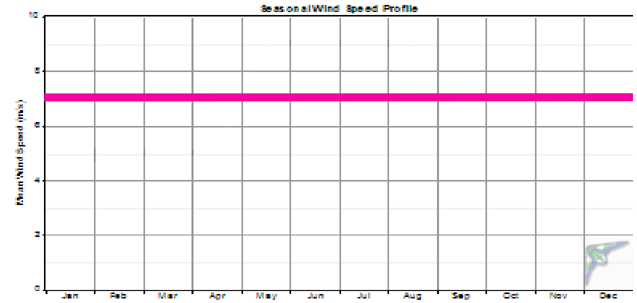


1/3 of year at 3 m/s
1/3 of year at 7 m/s
1/3 of year at 11 m/s

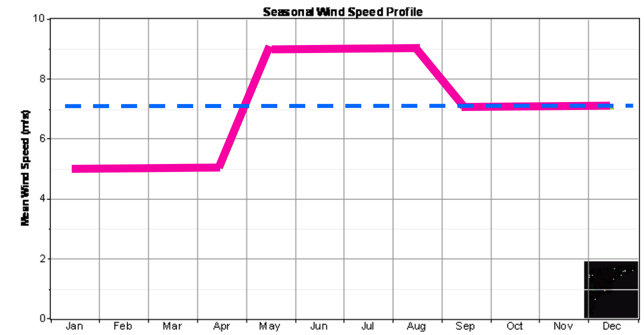


Not All 7 m/s Sites are the Equal !

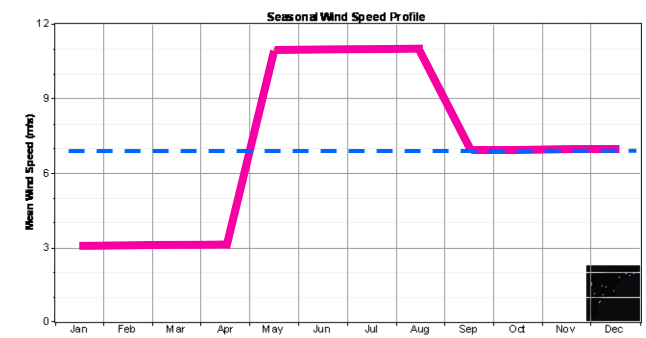
BASE CASE - STEADY WIND AT 7 M/S		
Annual Energy	1,878,107	kWh/yr
Annual Revenue/turbine	$112,686	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$22,537,284	$/yr/turb



WIND SPEED AT 5 - 7 - 9 M/S		
Annual Energy	2,466,956	kWh/yr
Annual Revenue/turbine	$148,017	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$29,603,471	$/yr/turb
Increase in Rev/Yr	$7,066,187	$/yr/farm
Energy & Rev Increase	31.4%	



WIND SPEED AT 3 - 7 - 11 M/S		
Annual Energy	3,912,763	kWh/yr
Annual Revenue/turbine	$234,766	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$46,953,158	$/yr/turb
Increase in Rev/Yr	$24,415,874	$/yr/farm
Energy & Rev Increase	108.3%	



Vertical Wind Shear Impact

LOW WIND SHEAR	0.120	
Annual Energy	121,192	kWh/yr
Annual Revenue/turbine	$7,271	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$1,454,300	$/yr/turb

HIGH WIND SHEAR	0.234	
Annual Energy	132,088	kWh/yr
Annual Revenue/turbine	$7,925	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$1,585,055	$/yr/turb
Increase in Rev/Yr	$130,755	$/Yr/farm
Energy & Rev Increase	9.0%	

Wind speeds - generally increase as you go higher above the ground.

Wind Developer wants to know:
How much does the wind speed increase as you go higher?

and

How much turbulence will the rotor experience?

Further Information / References

Web Based:

Wind Powering America http://www.eere.energy.gov/windpoweringamerica/

Federal wind siting information center: hppt://www1.eere.energy.gov/windandhydro/federalwindsiting/index.html

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